EXHIBIT 4

UNITED STATES DISTRICT COURT
DISTRICT OF MASSACHUSETTS

SINGULAR COMPUTING LLC,	Civil Action No. 1:19-cv-12551-FDS
Plaintiff,	
v.	Hon. F. Dennis Saylor IV
GOOGLE LLC,	
Defendant.	

REBUTTAL EXPERT REPORT OF SUNIL P. KHATRI, PhD.
ON THE VALIDITY OF THE ASSERTED CLAIMS

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IV. PATENTABILITY UNDER §101

A. The Asserted Claims Use Low-Precision Arithmetic to Solve a Technological Problem

[0255] In my opinion, the Asserted Claims use a precise low-precision circuit to solve a technological problem that was not otherwise resolved by the art.

[0256] Prior to Dr. Bates' inventions, modern digital computing systems relied on conventional graphic processors and central processors that included support for 16-bit floating point formats, alongside support for 32 bit floating point format which were designed for great precision, performing exact arithmetic. '273 Patent at col. 5 ll. 30-40. As explained in my Opening Expert Report, there was thus

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a need for Dr. Bates' LPHDR execution units working in parallel to achieve better performance than existing prior art systems. *See* Opening Rpt. at ¶¶62-68.

[0257] The Asserted Claims define LPHDR with very precise limitations. Claim 53 of the '273 Patent sets forth particular minimum levels of precision and specifies a dynamic range "at least as wide as from 1/1,000,000 through 1,000,000." '273 Patent at col. 32 ll. 1-12, 60-62.[18] Prior computing architectures did not include any such processing elements.

[0258] Those of ordinary skill in the art believed that massive amounts of Dr. Bates' LPHDR circuits were of little use. *See* '273 Patent at col. 7 ll. 5-11.

[0259] Prior art systems utilized full-precision execution units that take up space and are wasteful of transistors. *See e.g.* '273 Patent at col. 5 ll. 6-10.

[0260] The device of claim 53 of the '273 Patent substantially and structurally differs from devices in the prior art because it includes LPHDR processing circuits with particular parameters of precision and dynamic range. Prior computing architectures did not include such processing circuits.

[0261] Building the devices claimed in the Asserted Claims required the design and manufacture of hardware different from the hardware used in conventional processing units, since conventional hardware at the time was completely unsuitable to implement the inventions.

[0262] By deploying massive numbers of Dr. Bates' LPHDR execution circuits in conjunction with far smaller numbers of higher precision processing elements—at least 100 fewer—the device of claim 53 executes a far larger number of operations per clock period than a conventional computer while still supporting operations performed at a large precision and large dynamic ranges.

[0263] The Asserted Claims improved upon conventional computing by executing a far larger number of operations per clock period, while supporting software programs that require operations to be performed on numbers having high dynamic range, by: adding to a computer at least 100 LPHDR units, each LPHDR unit manipulating numbers having a dynamic range of at least 1,000,000 to 1/1,000,000, and each LPHDR unit's operations being imprecise by at least 0.05% for at least 5% of its possible valid inputs, and combining with that number of LPHDR units, a far smaller number of execution units that each execute the operation for multiplication on floating point values that are at least 32 bits wide, that far smaller number being at least 100 fewer than the number of LPHDR units in the computer.

[0264] The novel architecture of the device of the Asserted Claims yielded the following advantages over prior art computing devices: more efficient use of a computer's transistors, by requiring a far smaller number of transistors per multiplication operation done by the one or more LPHDR units than the execution units of conventional computers; the ability to collectively perform a number of operations per period as much as on the order of one hundred times larger than the number performed by a conventional computer having the same number of transistors, semiconductor fabrication process,

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[18] Claim 7 of the '156 Patent sets forth identical parameters for precision and dynamic range.

and power consumption; and while supporting software programs that require operations to be performed on numbers having high dynamic range.

[0265] I understand that in patent law, the patentability of a claim depends in part on whether that claim is directed to an "abstract idea." The Asserted Claims of the patents-in-suit are directed to computing devices that are constructed using circuitry that performs arithmetic using low-precision, high-dynamic-range representations. They represent innovations in the field of computer architecture, a field that studies the structure, operation, and performance of computers. Novel computer architectures are not "abstract ideas," as I understand that term.

[0266] The inventions of the Asserted Claims are not conventional and are indeed an improvement to computer technology. For example:

- Reducing the invention to practice required the design and manufacture of hardware different from the hardware used in conventional processing units, because conventional hardware at that time was unsuitable to implement the invention.

- The claimed advance to which the claims are directed was a computer that can execute a far larger number of operations per period than a conventional computer, while supporting software programs that require operations to be performed on numbers having high dynamic range, by adding to a computer at least 100 LPHDR units, each LPHDR unit manipulating numbers having a dynamic range of at least 1,000,000 to 1/1,000,000, and each LPHDR unit's operations being imprecise by at least 0.05% for at least 5% of its possible valid inputs; and further by combining with that number of LPHDR units, a far smaller number of execution units that each execute the operation of multiplication on floating point values that are at least 32 bits wide, that far smaller number being at least 100 fewer than the number of LPHDR units in the computer.

[0267] The patented inventions (claim 53 of the '273 patent, and claim 7 of the '156 patent) describe how the features of the claimed invention achieve an improvement in computer performance. The structure of the claimed inventions (claim 53 of the '273 patent, and claim 7 of the '156 patent) was new, unconventional and an improvement to computer performance. For example, the new, novel and improved computer architectures developed by Dr. Bates, provide for:

- the inclusion, within computer processors, of processing elements designed to perform low precision and high dynamic range (LPHDR) arithmetic operations.

- More efficient use of a computer's transistors, by requiring a far smaller number of transistors per multiplication operation done by the one or more LPHDR units than the execution units of conventional computers.

- Adding to a computer at least 100 LPHDR units, each LPHDR unit manipulating numbers having a range of at least 1,000,000 to 1/1,000,000, and each LPHDR unit's operations being imprecise by at least 0.05% for at least 5% of its possible valid inputs.

- Combining with that number of LPHDR units, a far smaller number of execution units that each execute the operation of multiplication on floating point values that are at least 32 bits wide, that far smaller number being at least 100 fewer than the number of LPHDR units in the computer.

B.   The Scope of the Asserted Claims is Well-Defined

[0268]   Dr. Gustafson criticizes the asserted claims use of the term "at least" as being too broad and not embodying a specific solution. *See* Gustafson Rpt. at Section XI.[19] The use of the term "at least", is common among computer scientists to define parameters and is a term that imposes boundaries on a claim. Moreover, skilled artisans commonly use the term in defining patent claims and its use does not render a claim "broad" or "open-ended. The use of the claim language "at least" establishes a range to represent both very small and very large numbers. In my opinion, there is sufficient definition to the claims such that requiring a range at least as wide as from 1/1,000,000 to 1,000,000 allows the claim to define a concrete technological innovation. Further, the requirement that for at least 5% of their possible inputs the LPHDR execution units produce an output value that has a *minimal* difference of 0.05% from the exact mathematical result further serves to define the precise characteristics of the numerical representations that are used by the claimed computing devices.

[0269]   For example, Dr. Gustafson notes that "because there is no *upper* bound either on the frequency or the difference, the claims encompass even an execution unit that, for every or nearly single valid input, has outputs that differ from the exact mathematical calculation by 100% or even more." Gustafson Rpt. ¶710. First, a unit that *always* outputs a result that is 100% wrong would serve no useful purpose, as Dr. Gustafson admits, and a person of ordinary skill in the art would understand that such a device would not be an "execution unit" that is adapted to execute a "first operation." Second, it is unclear what point Dr. Gustafson is trying to make with this hypothetical argument.

[0270]   Dr. Gustafson suggests that the "high dynamic range" limitation of the Asserted Claims is conventional because other number formats, such as the IEEE-754 format, have high dynamic range. Gustafson Rpt. at ¶¶705-706. IEEE-754, however, is not a low-precision format, and the Asserted Claims specifically require high dynamic range to be paired with low-precision. Performing computations on FP32 or FP64 (IEEE-754) representations requires arithmetic circuits that consume valuable resources, including space and energy. '273 Patent at 3:7-29.

[0271]   Low Precision: Dr. Gustafson further argues that by establishing boundaries for the degree of precision required by the claim, the patent does not disclose a concrete technological innovation. Gustafson Rpt. at ¶714. The notion of implementing low precision arithmetic in computing systems was contrary to the prevailing thought at the time, as was the concept of combining low precision with high dynamic range. *See* '273 Patent at 7:5-11 and 7:27-32. In my opinion, specifying the minimal degree of imprecision necessary gives the claim sufficient definition to allow the claim to define a concrete technological innovation. In my opinion, the use of the term "at least" within the

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[19] I note that Dr. Gustafson himself uses the term "at least" four times in the "Summary of Opinions" section of his report alone. Gustafson Rpt. ¶¶ 10-13.

Asserted Claims sets parameters for the dynamic range of possible inputs and allows the claims to embody a concrete technological innovation. The Asserted Claims improve the overall function of a computer by limiting the claimed LPHDR execution unit to defined parameters for both low precision and high dynamic range.

[0272]   In my opinion, the use of the term "at least" within the Asserted Claims sets parameters for the dynamic range of possible inputs and allows the claims to embody a concrete technological innovation.

V.   TRIAL EXHIBITS AND SUPPLEMENTATION

[0273]   I may rely on visual aids and demonstrative exhibits that demonstrate the bases of my opinions. Examples of these visual aids and demonstrative exhibits may include, for example, claim charts, patent drawings, excerpts from patent specifications, file histories, interrogatory responses, deposition testimony and deposition exhibits, as well as charts, diagrams, videos and animated or computer-generated video.

[0274]   Other than those referenced herein, I have not yet prepared any exhibits for use at trial in support of the opinions expressed in this report, but I expect to do so in accordance with the Court's scheduling order.

[0275]   I reserve the right to supplement my opinions, if permitted by the Court, after I have had the opportunity to review expert reports or other materials from Google, or if any other relevant materials are brought to my attention that might bear upon my opinions expressed herein.

I hereby declare that all statements made herein of my own knowledge are true and that all statements made on information and belief are believed to be true; and further that these statements were made with the knowledge that willful false statements and the like so made are punishable by fine or imprisonment, or both, under Section 1001 of Title 18 of the United States Code.

Date: March 3, 2023.

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Sunil P Khatri, Ph.D.